

Extracting γ and Penguin Parameters from $B_s^0 \rightarrow J/\psi K_S$

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Abstract

The $B_s^0 \rightarrow J/\psi K_S$ decay has recently been observed by the CDF collaboration and will be of interest for the LHCb experiment. It is the U -spin partner of the “golden” $B_d^0 \rightarrow J/\psi K_S$ channel and offers a determination of the angle γ of the unitarity triangle. Moreover, it allows us to control the hadronic penguin effects in the extraction of the B_d^0 - \bar{B}_d^0 mixing phase ϕ_d through a measurement of CP violation in $B_d^0 \rightarrow J/\psi K_S$. We discuss the picture emerging for these measurements from an LHCb feasibility study. While LHCb will be able to extract γ from the CP violation in $B_d^0 \rightarrow J/\psi K_S$, the main application of this channel will be the determination of hadronic penguin parameters. Such an analysis is actually needed in order to fully exploit LHCb’s impressive experimental precision for the determination of ϕ_d from $B_d^0 \rightarrow J/\psi K_S$. We give also the target regions for the effective lifetime of $B_s^0 \rightarrow J/\psi K_S$ and its CP-violating observables for improved measurements by CDF and the 2011 data taking at LHCb.

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1 Introduction

With LHCb taking data now, we have just entered a new era of precision flavour physics. This will allow us to implement new strategies for the extraction of the angle γ of the unitarity triangle (UT). One such method is offered by the $B_s^0 \rightarrow J/\psi K_S$ mode [1], which has recently been observed by the CDF collaboration [2]. As was also noted in Ref. [1], this channel allows us moreover to include the contributions from penguins to the determination of the B_d^0 – \bar{B}_d^0 mixing phase from the “golden” $B_d^0 \rightarrow J/\psi K_S$ decay. Including these effects will become mandatory in order to match LHCb’s impressive precision. To accomplish this task, the U -spin flavour symmetry of strong interactions is used to relate the hadronic parameters of the $B_s^0 \rightarrow J/\psi K_S$ and $B_d^0 \rightarrow J/\psi K_S$ modes to one another, as the decay topologies of both channels are related by interchanging all down and strange quarks.

Here we shall give a short summary of the prospects for implementing these measurements at LHCb. For a detailed discussion, including the derivations of the relevant formulae, an overview of the used feasibility study and further numerical results, the reader is referred to Ref. [3].

2 Extraction of γ

In the Standard Model, the $B_s^0 \rightarrow J/\psi K_S$ decay amplitude can be written as follows:

$$A(B_s^0 \rightarrow J/\psi K_S) \propto [1 - ae^{i\theta}e^{i\gamma}], \quad (1)$$

where the CP-conserving parameters a and θ characterise the penguin effects with respect to the colour-allowed tree-diagram-like contribution, which plays the dominant role. In order to determine the UT angle γ , as well as a and θ , the direct CP violation, C , the mixing-induced CP violation, S , and the observable $H \propto \text{BR}(B_s^0 \rightarrow J/\psi K_S)/\text{BR}(B_d^0 \rightarrow J/\psi K_S)$ have to be measured, which is the focus of our LHCb feasibility study.

For the penguin parameters, we use the results obtained in Ref. [4] from an analysis of the $B_d^0 \rightarrow J/\psi \pi^0$ decay as a guideline, $a = 0.41$ and $\theta = 194^\circ$; for γ , we assume a value of 65° . The resulting statistical errors are found as $\Delta C = \Delta S = 0.14$ and $\Delta H = 0.069$ for 6 fb^{-1} at a centre-of-mass energy of $\sqrt{s} = 14 \text{ TeV}$ (end of 2014–15), and $\Delta C = \Delta S = 0.035$ and $\Delta H = 0.052$ for 100 fb^{-1} (LHCb upgrade scenario).

Using the B_s^0 – \bar{B}_s^0 mixing phase as an input, we can determine contours in the γ – a plane, as illustrated in Fig. 1. Their intersection allows us to pin down both γ and the penguin parameters, and result in a statistical error for γ of 10° and 3.2° for our two LHCb scenarios.

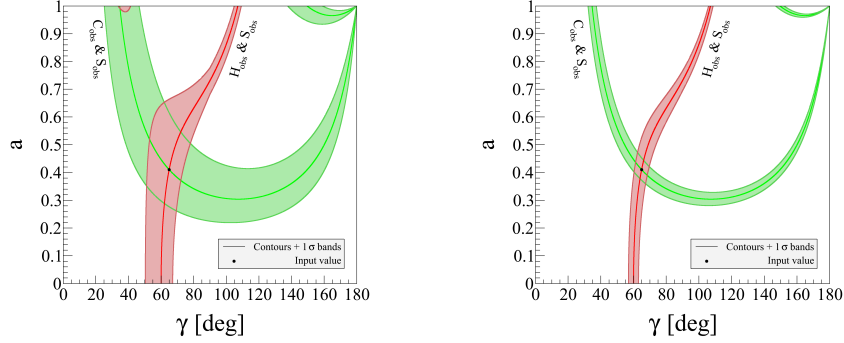


Figure 1: Determination of γ and a through intersecting contours, resulting from our LHCb feasibility study for 6 fb^{-1} (left) and 100 fb^{-1} (right).

Although these precisions for γ cannot compete with those from measurements of pure tree decays at LHCb, which give errors about three times smaller, the important aspect of this γ determination is that it may reveal a New-Physics (NP) contribution to the $B_s^0 \rightarrow J/\psi K_S$ decay amplitude. In the following, we assume that we will obtain a picture consistent with the Standard Model for γ , and that NP will only manifest itself in the $B_{d,s}^0 \rightarrow J/\psi K_S$ system through contributions to $B_{d,s}^0 - \bar{B}_{d,s}^0$ mixing.

3 Controlling Penguin Effects

The major application of $B_s^0 \rightarrow J/\psi K_S$ at LHCb will be the extraction of the hadronic penguin parameters (a, θ) and their control in the determination of the $B_d^0 - \bar{B}_d^0$ mixing phase ϕ_d from $B_d^0 \rightarrow J/\psi K_S$. The generalised expression for the measurement of this quantity reads [4]:

$$\frac{S(B_d^0 \rightarrow J/\psi K_S)}{\sqrt{1 - C(B_d^0 \rightarrow J/\psi K_S)^2}} = \sin(\phi_d + \Delta\phi_d), \quad (2)$$

where the hadronic shift $\Delta\phi_d$ encapsulates the penguin topologies. Since our goal is to minimise the U -spin-breaking corrections, we shall refrain from using the H observable and will assume that γ is known. In Fig. 2, we illustrate the determination of $\Delta\phi_d$ for our specific example, yielding $\Delta\phi_d$ errors of 0.79° and 0.19° for 6 fb^{-1} and 100 fb^{-1} , respectively [3].

In order to study the dependence on the input values of the penguin parameters for our analysis, we show the correlation between the hadronic shift $\Delta\phi_d$ and its statistical error at LHCb in Fig. 3. The corresponding curves show nicely that we can precisely determine the $\Delta\phi_d$ correction for a wide range of (a, θ) that should contain the “true” values of these parameters.

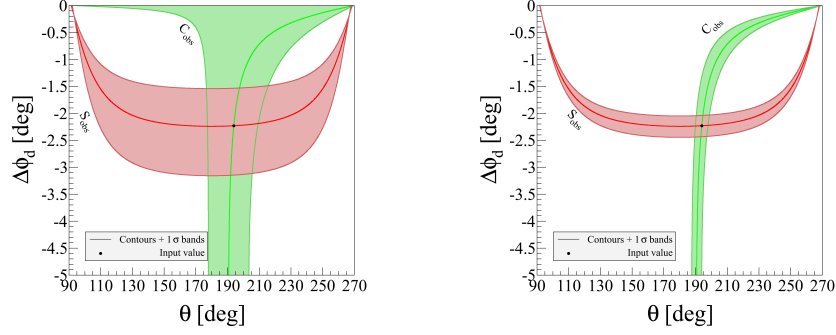


Figure 2: Determination of $\Delta\phi_d$ (left panel: 6 fb^{-1} , right panel: 100 fb^{-1}).

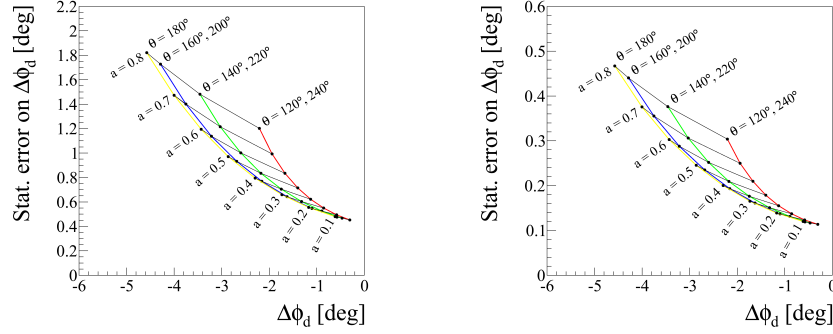


Figure 3: Correlation between $\Delta\phi_d$ and its error for our LHCb feasibility study for different values of a and θ (left: 6 fb^{-1} , right: 100 fb^{-1}).

It should also be noted that already a small penguin contribution with $a = 0.1$ gives a correction of $\Delta\phi_d \sim -0.5^\circ$.

In order to fully appreciate these results, $\Delta\phi_d$ should be compared with the expected statistical error on ϕ_d at LHCb, which is estimated as 1° and $(0.2\text{--}0.8)^\circ$ for 6 fb^{-1} and 100 fb^{-1} , respectively. In order to match these precisions, we definitely have to control the doubly Cabibbo-suppressed penguin contributions in $B_d^0 \rightarrow J/\psi K_S$. Looking at Fig. 3, we observe that we can actually achieve this goal. Measurements along these lines may eventually allow us to resolve CP-violating NP contributions to $B_d^0\text{--}\bar{B}_d^0$ mixing.

4 Physics with First LHCb Data

An interesting target for first LHCb physics results on $B_s^0 \rightarrow J/\psi K_S$ is its effective lifetime $\tau_{J/\psi K_S}$. In the SM, we find

$$\tau_{J/\psi K_S}/\tau_{B_s} = 1.060 \pm 0.020 |_{\Delta\Gamma_s^{\text{SM}}/\Gamma_s} \pm 0.010_{\text{Input}}, \quad (3)$$

where the last error corresponds to $a \in [0.15, 0.67]$, $\theta \in [174^\circ, 213^\circ]$ and $\gamma = (65 \pm 10)^\circ$ [4]. In the left panel of Fig. 4, we show the dependence on the B_s^0 – \bar{B}_s^0 mixing phase. In the right panel of this figure, we show the correlation between the mixing-induced $B_s^0 \rightarrow J/\psi K_S$ CP asymmetry and $\sin \phi_s$, which can be determined from the time-dependent angular analysis of the $B_s^0 \rightarrow J/\psi \phi$ channel. For a similar analysis of $B_s^0 \rightarrow K^+ K^-$ and more details on the effective lifetime, the reader is referred to Ref. [5].

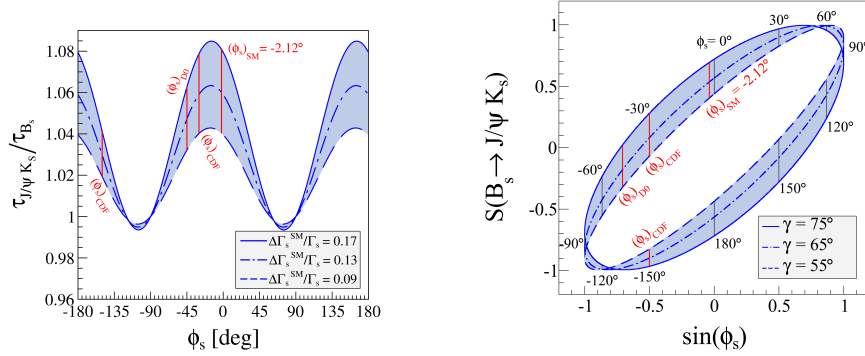


Figure 4: Left panel: dependence of the effective $B_s^0 \rightarrow J/\psi K_S$ lifetime on ϕ_s , right panel: correlation between $S(B_s^0 \rightarrow J/\psi K_S)$ and $\sin \phi_s$ for $\gamma = 65^\circ$.

We look forward to confronting these results with first data at LHCb! By the end of 2011 (1fb^{-1}), a $B_s^0 \rightarrow J/\psi K_S$ signal should be clearly visible, with a sensitivity of $\Delta C = \Delta S = 0.34$ for the CP-violating observables.

References

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